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CONTRIBUTIONS FROM THE BERMUDA BIOLOGICAL STATION FOR RESEARCH. — No. 5.

THE SHOAL-WATER DEPOSITS OF THE BERMUDA BANKS.

By Henry B. Bigelow.

With Four Maps.

THE SHOAL-WATER DEPOSITS OF THE BERMUDA BANKS.*

By Henry B. Bigelow.

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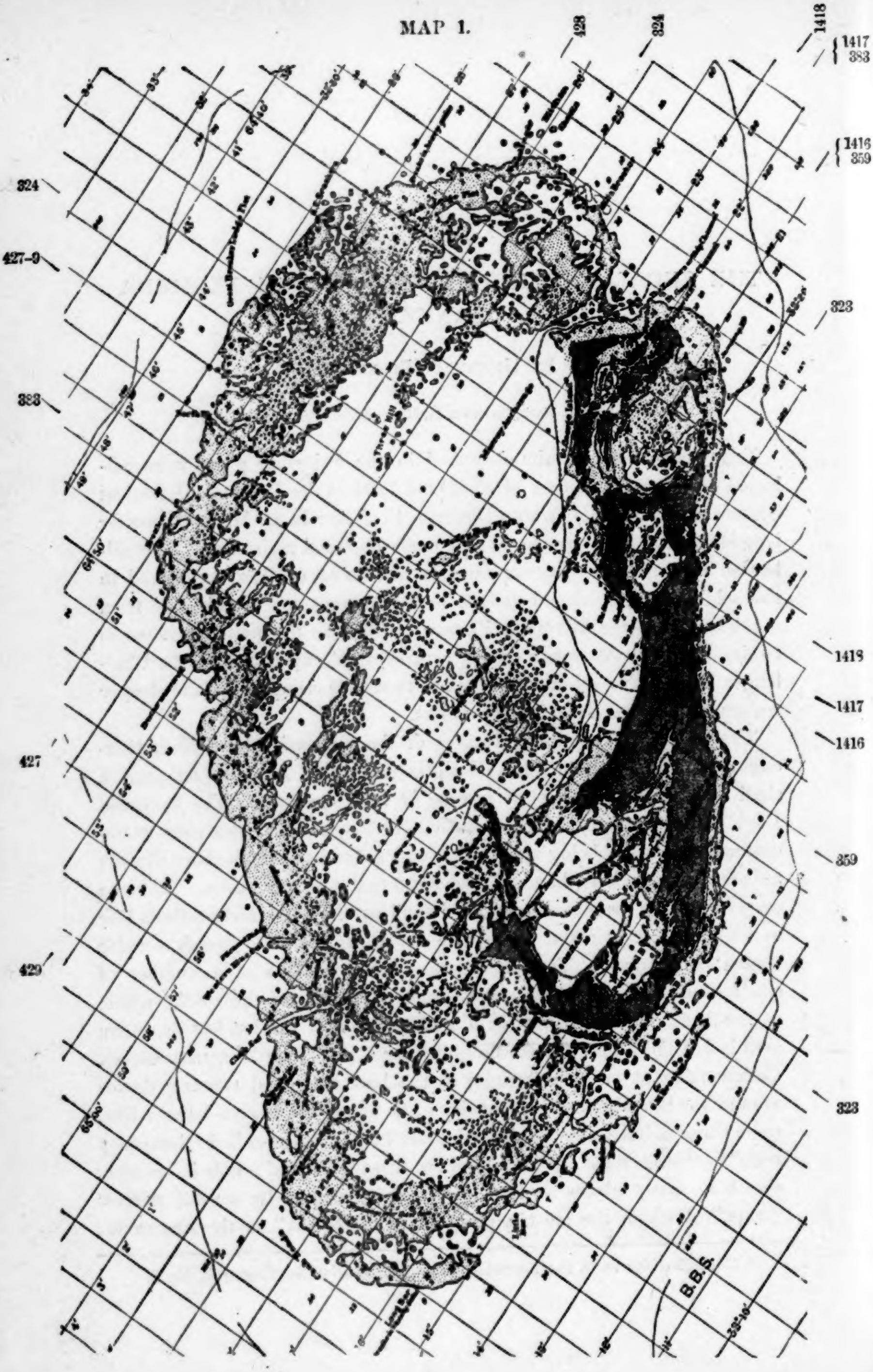
The sea-bottom deposits described in the following pages were collected during the summers of 1903 and 1904 at the Bermuda Biological Station for Research, to whose Director, Professor E. L. Mark, the writer is indebted for many courtesies and much practical assistance. The collection comprises seventy-six samples, the most of them preserved in alcohol, dredged at sixty localities in the lagoons and sounds, and from the beaches, of the Bermuda Plateau, as well as the material taken in twelve dredge hauls made during a three-days' expedition to the Challenger Bank. No attempt was made to secure samples in the deeper waters on the sea faces of the banks.

The general topographic features of the Bermudas have been thoroughly studied by Rein ('**81**), Heilprin ('**89**), and Agassiz ('**95**), and I shall commence with a brief résumé of their accounts. The Bermuda Bank (Map 1, p. 560) is oval in outline, its longest axis, which lies northeast and southwest, being about thirty miles, and its breadth about fifteen; an area of some two hundred and seventy-five square miles. For the purposes of the present description I shall consider the thirty-fathom line as its limit, for at about that depth the abrupt slope to deeper oceanic waters commences. The land mass, which consists of a number of small islands, lies in a somewhat crescentic form on the southern side of the bank, where it forms an almost continuous barrier, but its entire area is not more than fifteen thousand acres (less than 24 square miles). Commencing at either extremity of the land mass and running thence around the northern side of the bank, at about the twelve-fathom line, some three miles inside the thirty-fathom line, is the so-called "boundary reef," or "ledge flat." This is perhaps three-fourths of a mile in breadth, awash in many places at low tide, and penetrated by several narrow "cuts," of which the most important are "Hogfish," on the southwest;

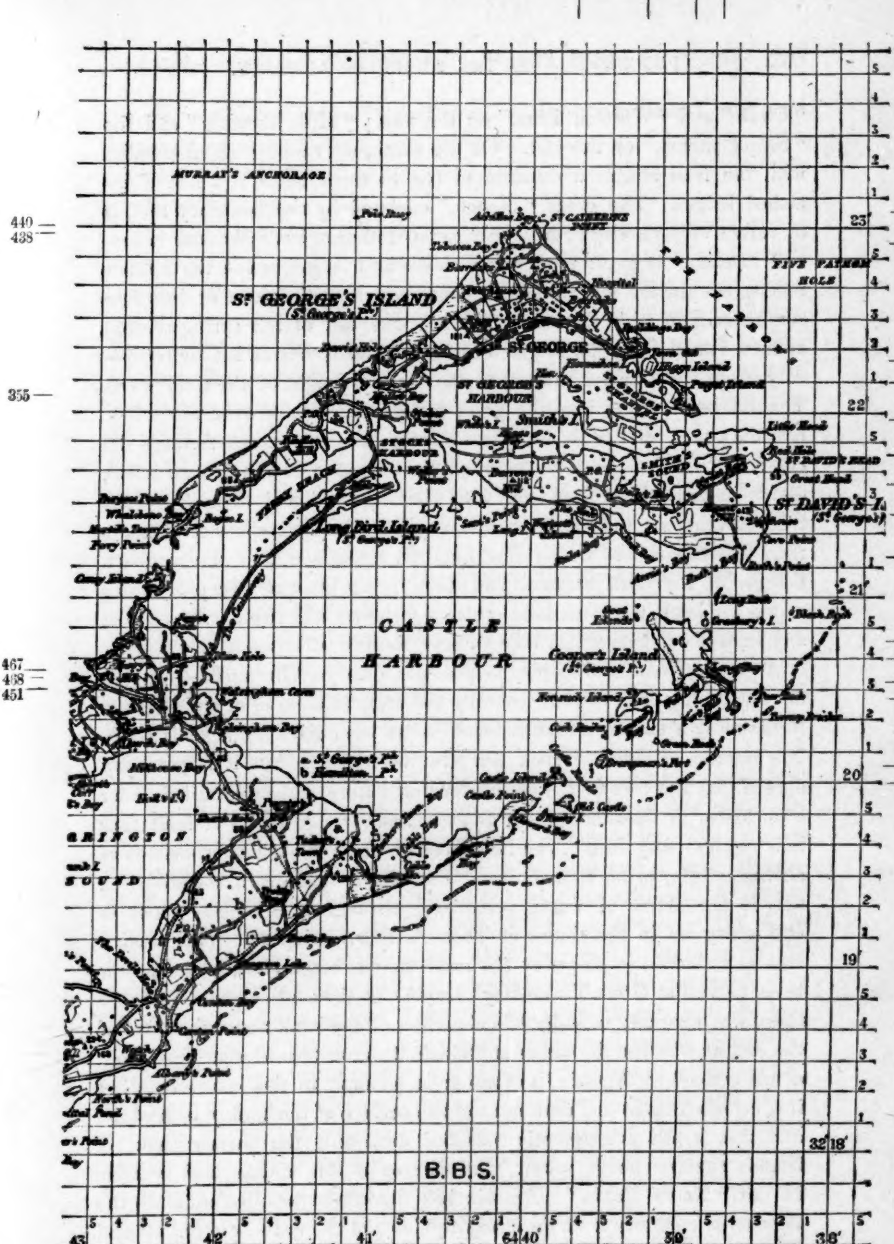
* Contributions from the Bermuda Biological Station for Research, No. 5.

MAP 1.



Map of Bermuda Plateau, based on British Admiralty Chart. Latitude and longitude ruled to minutes. One-hundred-fathom line in dots; Ship Channel in dashes; soundings in fathoms.

MAP 2.



Map of northeast third of Bermuda Islands, based on Ordinance Survey Map of 1902. Latitude and longitude ruled to 10 seconds. Scale about 0.9 inch to one statute mile.

"Chub" and "Western Blue," on the west; "Mills Breaker" and the "Ship Channel," on the east. On the southeast, running about parallel with the land and at a distance of one to three miles, is a line of detached ledges. The great "lagoon," enclosed by the boundary reef, is of rather uniform depth, from five to ten fathoms, but is broken in several localities by great numbers of shoals and ledges, while the Islands themselves enclose several large sounds, which are in more or less free communication with the sea. The rise and fall of the spring tides at Ireland Island (Map 4), as given on the admiralty charts, is four feet, — only about eight inches more than the vertical height of the tidal wave. The inflow of water into the great lagoon takes place over the whole boundary reef, so that it forms no strong currents, except through the cuts. On the bank as a whole, with the exception of one or two inlets, — for instance the Flatts Inlet into Harrington Sound (Map 3), — the tidal currents are too slight to cause any important transference of materials. Bermuda lies nearly one hundred miles south of the southern margin of the Gulf Stream, and there is no general sweep of water across the bank, while the land crescent forms an effective barrier against any surface currents which might follow the prevailing southerly winds.

A good account of the probable geologic history of Bermuda — a gradual upbuilding of a volcanic cone by the accumulation of organic débris, followed by a subsequent subsidence — has been given by Agassiz ('95). No outcrop of volcanic rock has ever been found, but it is generally agreed that the core of the bank is of that nature, although buried under a thickness of limestone which is estimated by Agassiz as at least four hundred and fifty feet. The limestone of which the islands consist is of aeolian origin, being formed from wind-blown sand by a consolidation due to the action of water percolating through it, a process which is still going on in the dunes at Tucker's Town (Map 2). This aeolian rock is underlaid in places by the much harder beach rock, which is now being formed at Great Turtle Bay (Map 4), on the south shore. Whether there was ever any considerable elevation of the bank above the level of the sea, or whether the dunes and sandhills were formed near that level, as maintained by Agassiz, is of no great moment in this connection, but it is certain that at one time most of the surface of the bank was dry land and that it has subsequently subsided until only the narrow chain of islands remains above water. An outcrop of this ancient land remains in the "North Rocks." Agassiz has described the formation of the lagoons as resulting from the breaking down of the walls between natural depressions owing to denudation combined with the destructive action of

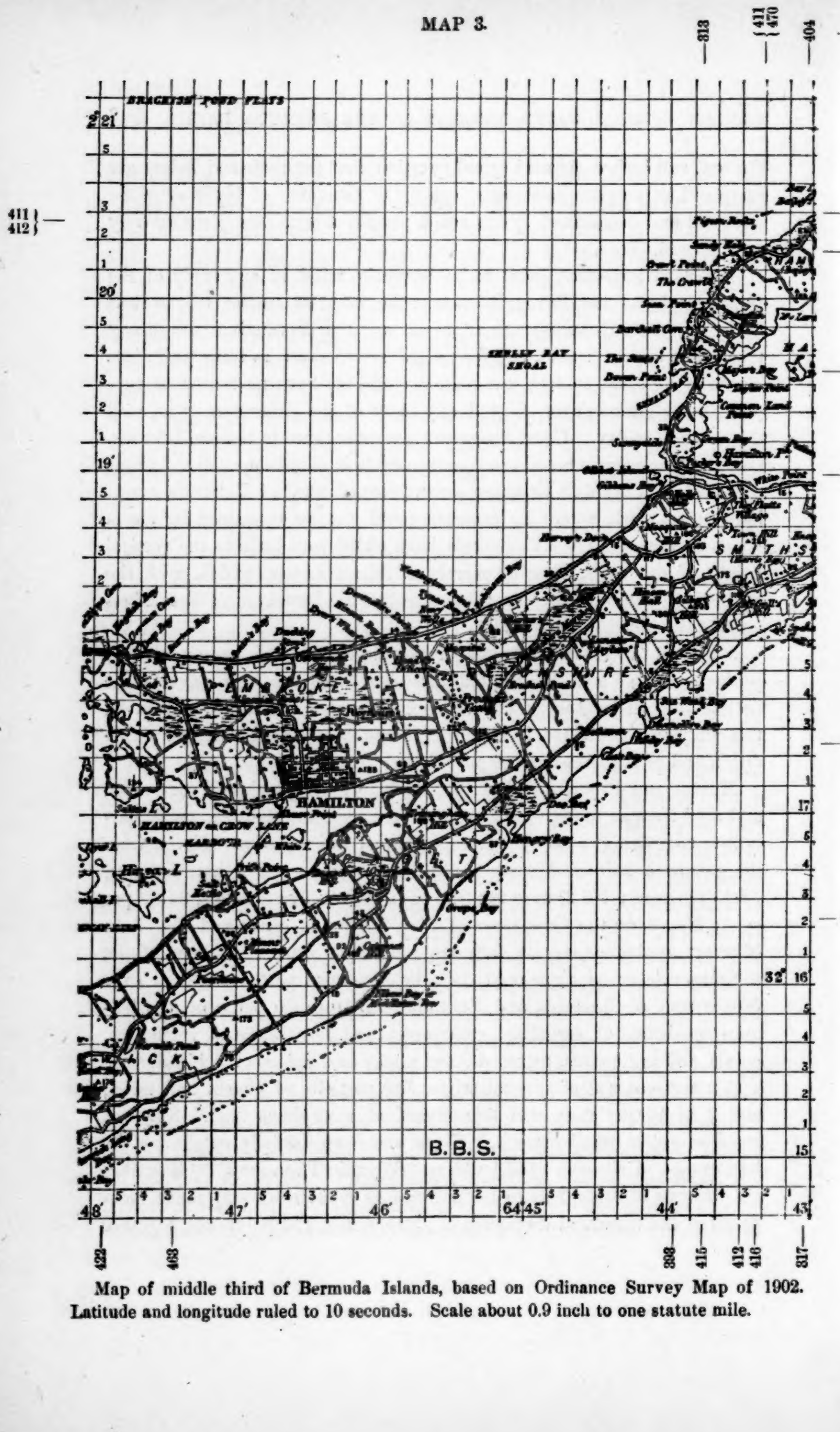
the sea, and he has shown beyond question that the reefs and ledges are composed of aeolian limestones, being the remnants of bluffs or cliffs, undercut and demolished by the sea, a process now taking place actively on the south shore.

The most important point to be borne in mind in any study of the physiography of the Bermudas is that the ring-like outline of the reefs bears no relation whatever to an atoll; and that Bermuda is not in any true sense a coral island, although coral grows there in some profusion. There is no coral reef on the plateau; and we have no reason to suppose that Bermuda ever showed any more of the characters of an atoll than it does to-day. Coral fragments are rather rare in the aeolian rock, though other organic remains are recognizable in abundance. Mr. Agassiz says (**'95**, p. 228) that he never saw a piece of coral in Bermuda above high-water mark where its presence could not be explained by storm winds or waves. The living corals have added very little to the vertical height of the reefs, forming merely a thin covering, which, with the encrusting masses of serpula tubes, protects the limestone of the ledges against the attacks of the surf.

Although the general features of the Bermudas, both geographic and geologic, are so well known, but little attention has been paid to the bottom deposits. Almost the whole information which we possess on this subject is contained in the brief accounts of the Challenger expedition and of Mr. Agassiz's explorations.

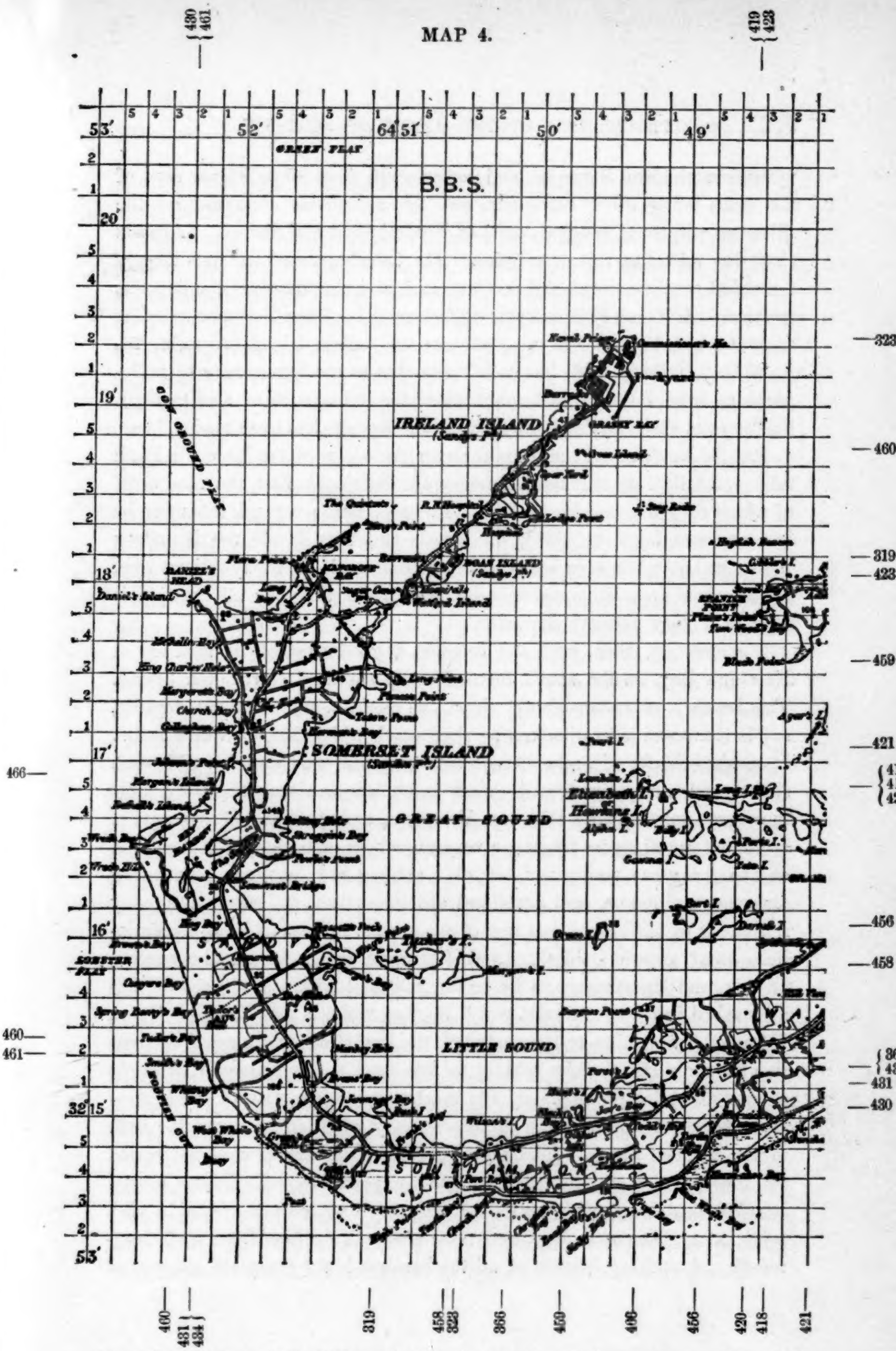
Murray and Reynard (**'91**, p. 48) analyze four samples of coral sand and mud from as many localities inside the reef, and find that calcic carbonate composes the following proportion of the deposits. No. 1, from the northern half of Murray Anchorage, in nine and a half fathoms, 95.43 per cent; No 2, near the Ship Channel, in five fathoms, 91.09 per cent; No. 3, on the Cow Ground Flat, 90.18 per cent; and No. 4, in Murray Anchorage, in six fathoms, 86.77 per cent. In three of the samples calcareous algae and their broken-down parts composed over 50 per cent of the mass, and Foraminifera, 10 to 30 per cent, the balance consisting of serpuline, gasteropod, and lamellibranch fragments, corals and millepores, ostracods, and plates and spines of echinoderms; 1 to 2 per cent was of mineral origin, fine particles of quartz and mica; and 2 to 10 per cent was fine flocculent amorphous dust. Siliceous remains are in small amount. These authors especially emphasize the importance of algae as sand builders. Wyville Thomson (**'77**) describes the bottoms in from four to ten fathoms as coral muds and sands, composed of the triturated fragments of algae, corals, and polyzoans, together

MAP 3.



Map of middle third of Bermuda Islands, based on Ordinance Survey Map of 1902.
Latitude and longitude ruled to 10 seconds. Scale about 0.9 inch to one statute mile.

MAP 4.



Map of southwest third of Bermuda Islands, based on Ordinance Survey Map of 1902. Latitude and longitude ruled to 10 seconds. Scale about 0.9 in. to one statute mile.

with Foraminifera, Serpulae, and gasteropods, from 85 to 96 per cent of the mass being calcic carbonate, and the remainder consisting of the siliceous spicules of sponges, casts of Foraminifera and diatoms. Agassiz ('95) has added to this description. He found some of the flats largely formed of coraline, coral, and aeolian sand, and characterizes the deposits westward of Wreck Hill and east of Ireland Island as a fine marl, similar to that which he found in the Bahamas, off Andros Island (Agassiz, '94, p. 253). Heilprin ('89) has called attention to the importance of millepores as sand builders, and emphasized the importance of aeolian sand. But beyond these no detailed study of the deposits has been made.

For the purposes of the present paper the whole of the Bermuda Bank falls naturally into four main topographic divisions: first, the land area, of which only the beaches can be considered here; second, the more or less enclosed lagoons; third, the shoals and flats inside the boundary reefs; and last, the area between these reefs and the thirty-fathom line. Of this last area little examination was made, and our information is only of a very general character.

Commencing, then, with the beaches, a good example is afforded at Newton's Bay, on the south shore, directly south of Harrington Sound. This beach is of rather abrupt slope, the angle being about ten degrees, and is composed of rather coarse shell sand, which has a pinkish color. It consists chiefly of broken fragments of gasteropod and lamellibranch shells, with many living gasteropods and a few bivalves; the three most important genera being Rissoina, Vermetus, and Tellina. Fragments of large and small worm tubes are very numerous, and the pinkish color is due to the great number of bits of a shining red Serpula. Incrusting Bryozoa, nullipores, and corallines are important, and there are many fragments of millepores, but few of any corals. Tests of large Foraminifera occur, chiefly Orbitolites and Orbiculina, with a few smaller species. In this sand there seems to be no fine material whatever; probably it is all washed away by the surf, which is often violent. At Tucker's Town (Map 2), a few miles to the eastward, the surf is causing a rapid destruction of the cliffs, thereby adding to the sand a large amount of finely ground material produced by the mechanical destruction of the aeolian rock, which, being light and therefore easily wind blown, forms the bulk of the modern dunes. The force of the winds here is well illustrated by the large shells found blown many yards inland. Many of the beaches contain enough serpuline fragments to give the sand a pink color, as at Newton's Bay, and none are entirely free from such fragments. A striking feature of all the beaches is the complete absence of

coral sand, though fragments of millepores play a considerable rôle as beach builders.

The detached ledges which run parallel to the south shore enclose a more or less clearly marked lagoon, with a depth of about six fathoms, where all conditions are as favorable for marine organisms as possible. Here mollusks, echinoderms, tube-building worms, gorgonians, corals, millepores, corallines, and nullipores flourish, and it is from this area that the beaches of the south shore receive most of their material. The amount of detritus added by the destruction of the cliffs varies in different places, but the total addition must be enormous, because the surf is often very violent. Most of the beaches, however, are swept clean of any of this fine calcareous silt, most of which is probably carried out and deposited in deeper water. Such parts of it, however, as are added to the beaches, as at Tucker's Town, are often blown far inland, to form large dunes. The gorgonians, which are luxuriant just off the shore, can of course add nothing but their spicules to the deposits, and the corals, being mostly porites, meandrinas, and other massive forms, are not easily ground up. The offshore reefs probably furnish most of the tubes of the red Serpulae and other worms and a few mollusk shells; but they are so well protected by incrusting Serpulae and algae that the surf cannot exercise any very vigorous destructive action on them.

Besides the beaches of the south shore, there are others on the north shore — as at Shelly Bay — and in Castle Harbor, — as at Tucker's Town and at Cooper's Island, — all of which consist of shell sand of the type already described, with the addition of a large proportion, probably 25 per cent, of very fine calcareous dust derived from the destruction of the neighboring cliffs and ledges. Here there is little or no surf action, and the slope of the beaches is not nearly so steep, being only about five degrees.

In the second class of localities fall also the landlocked lagoons or sounds. These are all more or less nearly enclosed bodies of water, of considerable size and moderate depth, standing in communication with the sea through several passages. The most important are Castle Harbor, St. George's Harbor, Harrington Sound, Great Sound, and Little Sound. It is generally agreed that they originated as depressions, or sinks, whose walls became broken through by denudation and the mechanical action of the sea. Several such sinks, now in process of formation, are occupied by marshes or marshy ponds, an example being Devonshire Marsh. Some, perhaps many, of the channels which connect the sounds with the open sea originated as partially subterranean channels, such as to-day connect Harrington Sound with the surrounding waters.

Castle Harbor, which is an excellent example of one of these large submerged sinks, communicates with the sea through several channels, so that it is comparatively open. The main portion of the harbor is about three miles in diameter, is nearly round, and has a greatest depth of about seven fathoms; but the bottom is very uneven. On the south it is separated from the ocean by a chain of small islands, between which there are five narrow channels. On the northwest the enclosing wall is more nearly complete, being broken in only one place, — by the body of water known as Ferry Reach, a partially artificial basin nearly cut off from the harbor by a causeway and an island, but communicating on the west with the open water of the great lagoon, and on the northeast with the passage known as Stocks Harbor. Through this passage Castle Harbor connects directly with St. George's Harbor and through it with the outer lagoon. Thus Castle Harbor, communicating with the sea on three sides, combines the advantages of a protected location and a free circulation of water, making it a very favorable locality for many marine organisms. The bottom is of clear white sand, interrupted by numerous ledges covered with corals, millepores, and coralline algae.

A sample of this sand from Station No. 356, near Castle Island, shows the following composition. It is white, slightly flecked with pink and yellow, slightly coherent, sticky; with 20 per cent of fine flocculent amorphous calcareous ooze. Foraminifera are a striking feature, forming 40 per cent or more of the mass; particularly abundant are the large sand-dwelling genera Orbitolites, Orbiculina, and Ammodiscus. A partial list comprises Orbitolites duplex, Orbiculina adunca, Ammodiscus tenuis, Cornuspira foliacea, Pulvinulina menardii, and species of Polystomella, Trochammina, Textularia, Cyclammina, Cassidulina, Biloculina, and a very few Globigerinae. The great majority of them are living, though there are in addition many dead tests and casts. Most important after the Foraminifera are the coralline algae Udotea and Halimeda, which Agassiz ('88ª, p. 82) has also described as occurring in great masses on the Florida Reef. In this particular sample they form only about 10 per cent, but in certain parts of Castle Harbor they grow in such great abundance that their remains form 30 per cent to 40 per cent of the sand. Living mollusks and their shells, mostly fresh and little worn, form 10 to 15 per cent, the most important genera being the gasteropods Bulla, Codakia, Nassa, Cardium, Gouldia, Rissoina, Olivella, Modulus, Bittium, Cadulus, and Vermetus, and the bivalves Crasinella, Abra, Macoma, Semele, Arca, Lasaea, and Tellina. The remainder consists of serpuline fragments, of millepore,

bits of coral, echinoid plates and spines, starfish pedecillariae, holothurian plates, sponge spicules, and a few diatoms. The fine flocculent dust or ooze, mentioned above as forming 20 per cent of the sample and giving it a sticky consistency, is composed of exceedingly minute amorphous calcareous particles. It is identical with the ooze, which, in larger deposits, has already been described by Agassiz ('**94**, p. 52, and '**95**, p. 253) as "marl," and is undoubtedly produced by the slow triturating action of the sea on aeolian rock. The fine dust thus formed is held so easily in suspension in the water that it is carried and deposited, often at a great distance from its point of origin, in all localities where absence of wave action or currents allows. It is present, in greater or less degree, in every bottom sample from the Bermuda Bank.

As a whole, this bottom contains a great number of living organisms, and the empty shells and shell fragments are fresh and but little waterworn — good evidence that they are of very recent deposition. But at Station 1412, at about the centre of Castle Harbor, in four fathoms of water, the proportion of fine calcareous silt is very much greater, living organisms are less numerous, and the whole sample has a much more water-worn appearance; while the honeycombed condition of most of the dead shells shows that solution by the sea water is here of some importance. This sample was taken from a small basin nearly surrounded by shoals and ledges, where so much of the fine detritus formed by the mechanical action of the water on these aeolian rocks, together with the various organic remains, is being constantly deposited on the floor of the basin that it effectually chokes most of the living organisms. In such regions as Castle Harbor, and, in fact, over most of the Bermuda Plateau, where the sea water always holds a vast amount of calcareous silt in suspension, fixed and sand-dwelling organisms, such as mollusks, tube-building worms, bryozoans, and hydroids, reach an extensive development only on such bottoms as have an active circulation of water that prevents the rapid deposit of silt.

Castle Roads is a good example of the deeper channels connecting Castle Harbor with the open sea on the south. This passage is about four hundred yards wide, with a greatest depth of about six fathoms, and during both incoming and outgoing tides a strong but not violent current runs through it.

The bottom at Stations 409 and 1413, in five fathoms, is a rather coarse shell sand, containing many large fragments; most of the organisms are macroscopic. It is white, spotted with pink; very clean, with less than 1 per cent of fine ooze. Foraminifera of the same species as

those already enumerated from Castle Harbor form about 25 per cent of the deposit; bivalves and gasteropods, many of them living, about 25 per cent; the remainder consist chiefly of calcareous algae, and fragments of millepore, much water worn, with a few Serpula and Polyzoa. Except for the abundance of living organisms, the resemblance of this sand to the beach at Newton's Bay is striking.

Nonsuch Scaur, between Nonsuch and Cooper's Islands, a shoal channel with only two fathoms of water, has a bottom at Stations 407 and 408 of very distinct character, and is a good example of the shallow passages. The bottom is white sand with a faint yellowish tinge, and many pink fragments. It is fine, the average diameter of the fragments being about 1 mm., granular, with about 3 per cent of fine ooze. Foraminifera, — many of them living, the most abundant being Orbitolites and Polystomella, — corallines, and millepore fragments in about equal proportions form 60 per cent of the mass, the remainder being fragments of bivalve and gasteropod shells, Serpula, spines and plates of echinoids, Polyzoa, calcareous spicules, diatoms, and about 5 per cent of rather large, rounded, amorphous calcareous fragments, evidently the coarser detritus from the cliffs on the neighboring islands. Except for the Foraminifera, there are very few living organisms; and this is apparently an area where deposition of sand from the nearby ledges is going on rapidly; its exposed position, however, and the vigorous wave action thoroughly scour the bottom.

In Ferry Reach, the miniature artificial sound on the north of Castle Harbor, the bottom is white sand. A sample near its mouth, Station 402, in three fathoms, is white, mottled with yellowish, rather fine, granular, uniform, with about 10 per cent fine ooze. Foraminifera and their casts form about 10 per cent; joints of the calcareous algae Halimeda and Udotea, and their broken-down fragments, form about 30 per cent; the remainder, consisting of millepores, bivalves, gasteropods, Serpula, coral fragments, ostracods, echinoid fragments, holothurian plates, sponge and alcyonarian spicules, diatoms, and a few radiolarians.

At the inner, southern end of the Reach the bottom is grayish white, coherent, with about 30 per cent ooze, the remaining 70 per cent consisting of the same organisms as above, in about the same relative abundance; whereas at the northern entrance there is less than 2 per cent of fine ooze, and the bottom in every way closely resembles that at Nonsuch Scaur.

In the small basin known as Stocks Harbor there are few ledges and very little living coral. The bottom consists of grayish sand, composed

of a small amount of broken shells and a larger amount of fine silt, most of which is either white marl or of terrigenous origin.

St. George's Harbor is an enclosed sound of much smaller area than Castle Harbor, and is much more nearly landlocked, its only direct communication with the sea being through three narrow channels on the northeast, two of which are shallow. On its northwest border there is a considerable bight, Mullet Bay by name, with a shoal bar at its mouth; and at the southern end Smith's Island cuts off Smith's Sound and Dolly's Bay, which together form another practically enclosed bight. The greatest depth of St. George's Harbor is seven fathoms, and the chief tidal current is through St. George's Channel. The bottom samples at seven fathoms consist of a rather coarse dark gray sand of very much water-worn shell fragments, together with the plates and spines of Toxopneustes, a few large Foraminifera, and the calcareous alga Halimeda. There are very few living organisms of any kind, and there is a considerable proportion, about 30 per cent, of fine calcareous silt, which is of limestone origin, but, unlike the "marl" already mentioned, of a bluish gray color. On the north side of the Harbor, between Horseshoe and St. George's islands, in two fathoms (Station 448), the bottom is fine grayish blue sand, coherent, with 75 per cent fine ooze. Foraminifera, especially Polystomella, form 10 per cent, and nullipore, gasteropod, bivalve, millepore, and echinoid fragments, 10 per cent. The fine ooze consists almost wholly of impalpable, flocculent, amorphous, calcareous dust, stained gray; probably in large part of terrigenous origin and very similar to the bottom at Mullet Bay. Although this passage communicates with the sea, it is closed by a very shoal bar; it is a region of rapid deposition and with few living organisms.

The cut between Horseshoe and Paget islands (Station 447) is deeper. A sample from three fathoms at the inner end of the cut is dark blue sticky mud, slightly coherent; 50 per cent fine ooze; Foraminifera,— especially Polystomella biloculina, Orbitolites, Hastigerina, and Textularia,— 15 per cent; the remainder being calcareous algae, millepores, and mollusks in about equal abundance, with a few Serpulae and Polyzoa. The fine ooze is of the same composition as in the last sample and there are few living organisms except the Foraminifera. The coarse portion of the sample is evidently water-worn reef detritus swept in through the channel by the tides.

In St. George's Channel, the chief passage between St. George's Harbor and the outer lagoon, the bottom is bluish gray mud, of the same composition as in the Harbor, the proportion of coarse sand

increasing rapidly toward the mouth; a sample from the middle of the opening (Station 1409, four fathoms), just at the mouth, has only a very faint bluish tinge. It is rather coarse, clean, granular, with 1 per cent fine silt. Foraminifera make up 10 per cent, and millepores and algae, in nearly equal proportion, about 40 per cent; the remainder consists of bivalve and gasteropod fragments, Serpula, Polyzoa, echinoid fragments and small water-worn fragments of limestone from the cliffs. There are many living organisms in this bottom, especially Foraminifera and gasteropods, but the greater portion of the deposit consists of the coarser reef detritus from the neighboring ledges.

Mullet Bay, on the northwest side of St. George's Harbor, is a small nearly enclosed body of water cut off by a very shoal bar and with no tidal currents. The depth over the bar is about seven feet, that inside the bay nearly three fathoms. The bottom (Station 355) consists of a sticky and very fine blue mud, which is chiefly if not entirely calcareous. The fragments of which it is composed are so minute as to be wholly indistinguishable to the naked eye. Large numbers of Toxopneustes live in this mud, and it contains great quantities of their plates and spines, but there are few if any other conspicuous living organisms. The character of the mud shows conclusively that it is chiefly terrigenous silt and detritus washed down from the surrounding hills, and it corresponds perfectly in its occurrence and origin to the siliceous "blue mud" of the continental slope, its calcareous nature being of course explained by the fact that the land mass consists entirely of limestone rocks.

Dolly's Bay (Station 1408), another partially landlocked bight of a similar character, has a bottom of the same type consisting almost entirely of sticky blue mud, with a few echinoid plates and spines. In Smith's Sound (Station 1407), which connects Dolly's Bay with St. George's Channel, the bottom is of similar constitution, but much coarser, with a considerable number of both broken and living shells and an appreciable proportion of the spicules of calcareous sponges, gorgonians, and holothurians.

A glance at the maps shows the close correlation between the bottom deposits and the topographic features in the Castle Harbor and St. George's Harbor regions. In Castle Harbor we find a large body of water, of moderate and fairly uniform depth, in rather free communication on two sides with the sea, and with a free circulation of water, though without strong tidal currents. Under these favorable conditions there is a considerable development of stony corals, gorgonians, and millepores; mollusks, worms, and echinoderms also flourish in great

numbers. These living organisms, particularly mollusks, millepores, and Foraminifera, are adding constantly to the bottom deposits, except in some parts of the basin, where silt from the limestone ledges is deposited in such large quantities as to practically choke them. In the deep channels on the south, such as Castle Roads, the tidal currents, setting now in one direction and now in the other, make conditions for sedentary animal life still more favorable, by the great access of fresh sea water and the continual scouring which they effect. In St. George's Harbor the conditions are somewhat different. This is much more nearly enclosed, and the channels which connect it with Castle Harbor and with the outer lagoon are very much shoaler than its main basin, the result being that the circulation of water is not rapid, and a considerable quantity of terrigenous detritus settles to the bottom, giving the sand its characteristic gray color. This detritus, added to the calcareous silt from the outer lagoons, is in sufficient quantity to prevent any very active development of animal life on the bottom. In Dolly's Bay and Mullet Bay the same process has gone so much further that the whole bottom is covered to a considerable depth with the blue mud, which is chiefly of terrestrial origin. In St. George's Channel the tidal current is strong enough to scour the bottom of most of this fine material, leaving little but the large fragments.

The much larger basin at the western end of the islands, known as Great Sound, agrees, in many of its topographic features, with Castle Harbor. Like the latter, it probably originated as an enormous sink, which, through the combined action of subsidence and of the denudation of its surrounding hills, has become open to the sea. In its present form it is open on the north by a passage about a mile and a half broad, and on the west by the narrow cuts which separate Ireland Island, Somerset Island, and the main island. The southern part of this large basin is practically cut off by several small islands, forming the smaller basin known as Little Sound, while Hamilton Harbor forms a narrow arm on the east. The greatest depth of Great Sound, about eleven fathoms, is near its southern border; passing thence northward, the water shoals steadily until at the narrowest point, between Ireland Island and Spanish Point, many of the ledges are nearly awash at low tide, thus forming a natural bar. Through this a narrow ship channel has been blasted.

The character of the bottom in the different regions of Great Sound varies considerably. Near the entrance (Station 459) there are numerous luxuriant patches of gorgonians, sponges, millepores, and corals, which alternate with spaces of white shell sand, composed chiefly of calcareous

algae and molluscan remains, with about 10 per cent of fine calcareous silt. Further south, east of Boaz Island and Somerset Island, in a depth of about four fathoms, the appearance of the bottom is altered by the complete absence of coral patches or ledges, although there is still a small amount of living, and a good deal of dead, coral. The bottom samples here consist of white sand, in which fine and coarse material are in about equal amount. The former is about 60 per cent calcareous silt or marl, the remainder being calcareous spicules, together with a great variety of small organic particles. The coarse material consists chiefly of algae, millepores, molluscan fragments, and living mollusks, with worm tubes and echinoid plates. There are very few Foraminifera and few coral remains, although there are a considerable number of millepore fragments. As we go still further southward into the sound, we find the bottom near its southern edge in ten fathoms, composed of sticky white sand of similar constitution but containing a much larger proportion of fine ooze. Apparently this deep basin is a region of deposition for the silt collected by the water on the outer flats.

On the south and east sides of Great Sound, between the different islands, there are several shoal bars where the sand is sufficiently distinctive to be worth special notice. On the bar between Tucker's and Morgan's islands, which forms the southern boundary of Great Sound and the northern boundary of Little Sound (Station 458), in three fathoms, the bottom is whitish, thickly mottled with bright yellow, rather coarse, granular, clean sand, with 6 per cent fine ooze. The yellow color is due to a staining of many of the fragments. Large Foraminifera, of the same genera as those found in Castle Harbor, together with their casts, form about 20 per cent; calcareous algae, bivalves, and gasteropods, 60 per cent; the remainder being composed of Serpula, echinoid spines and plates, millepore, and coral. There are many living Foraminifera and mollusks in this bottom.

The same type of sand, of the same yellow color and with many living mollusks, forms the bars between Godet Island and the main island (Stations 463 and 464), and between Moses and Darrell islands (Stations 456 and 457) on the east of Little Sound; it also forms the bottom off the north and west sides of Elizabeth Island (Stations 455 and 456). But in the channel leading into Hamilton Harbor (Station 421), the sand, though yellowish and almost free from ooze, is much finer, contains very few living organisms, and consists chiefly of water-worn fragments of algae, mollusks, and millepores. It is probably an area for deposition of material from the surrounding shores and shoal bars; but all the finer detritus is scoured out by the tide.

Little Sound, situated directly south of Great Sound and forming a basin about two miles long, with a greatest depth of ten or eleven fathoms, is in many respects similar to Mullet Bay. On the south, east, and west it is bounded by the shores of Long or Bermuda Island; its eastern edge is formed by a broad and very shallow flat, with three small islands; and on the north it is separated from Great Sound by a shoal and narrow bar, over which the greatest depth of water is three fathoms. There is no channel cutting this bar, so that the sound is a practically enclosed basin. The bottom at Station 366, in nine fathoms, is composed of a fine, sticky blue mud, made up of extremely minute particles, most of which are of terrigenous origin. But I was able to distinguish also the tests of a few small Foraminifera, as well as a large number of calcareous sponge and gorgonian spicules, and fragments of Halimeda. The only large fragments were a few broken and water-worn lamellibranch shells, and the bottom contains very few living organisms. It is evident from the nature of the bottom that its origin is very similar to that of Mullet Bay, and that much of the mass consists of terrigenous detritus washed down from the hills which form its southern shore. The topography of Little Sound is such that it has acted as a catch-basin for this material and also for the fine calcareous silt from the outer lagoons and reefs, carried in suspension by the sea water. The absence of living organisms is the result of a choking process caused by the rapid deposition of silt all over the bottom; and in such a locality the remains of resident animals are of very slight importance in forming the bottom deposits.

Hamilton Harbor shows somewhat similar conditions, with a bottom of the same type. There is also another basin of this type which, though very much smaller, has a depth of nine fathoms; it is known as "Granaway Deep," and lies directly south of Marshall Island.

Harrington Sound is more completely landlocked than any of the basins hitherto described. At its southwest corner it connects with the open lagoon through the "Flatts Inlet," a channel barely sixty feet wide, and by several smaller subterranean passages. I cannot make any estimate of the amount of water which passes in and out through these channels, but in certain parts of the sound the tidal currents are of appreciable strength. Strangely enough, in spite of its landlocked condition, this sound is one of the richest localities for invertebrate life; from which we must draw the conclusion that its circulation of sea water is probably much greater than the narrowness of the known passages connecting it with the outer lagoon would indicate. The greatest depth is said by Heilprin ('89) to be sixteen fathoms; most of the basin is

from six to ten fathoms deep. The bottom (at Station 404, one fathom), just off the beach at Trunk Island, is grayish white, mottled with red, brown, or yellow; it is composed of coarse sand, the largest fragments 15 mm. in diameter, and about 1 per cent fine ooze. This bottom differs markedly from any hitherto mentioned. There are very few Foraminifera, not more than 2 per cent; echinoid plates and spines, coralline algae, alcyonarian spicules, mollusks, corals, and polyzoans together form not more than 20 per cent; the remaining 75 per cent consists almost wholly of limestone fragments, ranging in diameter from 1 to 15 mm., of rounded and irregular shapes, and variously stained red and brown. They are the coarsest detritus from the neighboring cliffs.

In four fathoms of water, between Rabbit Island and the shore (Station 470), the sand is of the same color and composed of the same elements, but much finer, and with 5 per cent fine ooze. There are no large fragments, and the particles are of fairly uniform size, 1–5 mm. in diameter. The sand decreases in coarseness from shoal water near the shores to greater depths, with an increase of fine ooze; a sample from eight fathoms consists of very fine sand with 30 per cent ooze, and a few large fragments of dead coral. Living organisms seem to have added very little to the sands of Harrington Sound. The undercut and water-worn condition of the cliffs, and the huge limestone masses recently detached from them, bear witness to the effects of surf action on soft friable limestone, even in so limited an area as the Sound. Enormous quantities of detritus, both coarse and fine, must be constantly added to the beaches, the former remaining in shallow water, the latter being swept out and gradually deposited in greater depths beyond the reach of wave action. The bottom in this sound is more extensively derived from broken-down limestone than that of any other extended area which I have examined, and I believe that it is being added to with greater rapidity.

The most important and widespread of all the formations of sand that are now taking place occur on the northern side of the main islands, between them and the nearly continuous boundary reef. Both Heilprin and Agassiz have shown that this area consists of a series of sunken lagoons, bounded by more or less continuous ridges, the "Flats." At only one spot, the "North Rocks," do any of the flats rise above sea-level, but the depth in many places is so slight that they are nearly awash at low tide. The numerous ledges and shoal patches, although covered by a luxuriant growth of corals and gorgonians, are not of coral origin, but are ledges of the ordinary aeolian rock, over which the corals

and other organisms are growing, and they furnish a great deal of material to the bottom sands. The depths of the lagoons are fairly uniform and moderate, being nowhere over twelve fathoms. The more important lagoons from which I have examined samples are Mangrove Bay, the Cow Ground Flats, Green Bay, Murray Anchorage, the Ship Channel, and Brackish Pond Flats.

Mangrove Bay, though open to the sea, is nearly surrounded by Somerset Island and, on the north, by a shoal flat, making it another enclosed catch basin, with a greatest depth of six fathoms. The bottom at Station 319, in five fathoms, is fine gray sand, containing many large fragments of millepore and oculina, evidently washed from the neighboring flat. The bulk of the sand consists of broken shells, sea-urchin plates and spines, and fragments of worm tubes, with about 20 per cent of very fine calcareous silt. The presence of great numbers of the calcareous spicules of sponges and gorgonians, and of the tests of small Foraminifera, show that it is of reef origin; a small proportion of it, however, is apparently terrigenous silt, or "blue mud," and there are few living organisms. Most of this bottom is evidently derived from the surrounding shoals, being composed of various animal remains, together with a large amount of the fine silt resulting from the erosion of the limestone ledges. The rest of the material is of terrigenous origin, and resident organisms have had little or nothing to do in the formation of the deposit.

Murray Anchorage is the largest of the submerged lagoons, covering an area of about ten square miles. It extends from the shores of St. George's Island on the southeast to the Three Hill Shoals on the north, a distance of three or four miles. On the southwest it is bounded by Bailey's Bay Flats, and on the northeast by the boundary reefs to the north of St. George's Island. The bottom is level, with very few shoals or ledges, and the greatest depth, in the Ship Channel on the southern edge of the lagoon, is ten fathoms. The deposits over the bottom of the lagoon vary considerably in character in different localities, although they are everywhere white sand. North of Murray Anchorage, between Three Hill Shoals and the boundary reef at Station 324, in ten fathoms, this white sand consists of exceedingly minute particles, and has the appearance of a white, chalky ooze. Fragments of algae, millepores, and gasteropod and lamellibranch shells, with a few echinoid fragments and pieces of worm tubes, are distinguishable; also a few Foraminifera. Over 70 per cent of the mass, however, consists of minute calcareous particles, forming a true marl. There are very few living organisms of

any kind on this bottom, and their remains have added but slightly to it. The fine silt consists of the detritus from the destructive action of the water on the surrounding limestone reefs and ledges. In the southern and southeastern part of the lagoon, through which the Ship Channel runs, the character of the bottom is very different. We find here also, at Station 1416, in seven fathoms, a white sand, but it is much coarser, containing large quantities of corallines, molluscan shell fragments, and many living bivalves and gasteropods, with bits of worm tubes, plates of echinoids, millepore fragments, and a few large Foraminifera, chiefly Orbiculina and Orbitolites. There is about 10 per cent of fine calcareous silt, containing some spicules of sponges and gorgonians, which is similar in nature to the white marl of the northern half of the lagoon. This shell sand extends westward along the Ship Channel, at a depth of about eight fathoms, into the so-called "Brackish Pond Flats," directly north of the Flatts Inlet. In this inlet itself (Station 393), the very strong tidal flow has effectually scoured out all the finer materials, leaving only the coarser fragments. From the Ship Channel southward toward Crawl Point and Bailey's Bay, the water gradually shoals to about four fathoms; about a mile off shore, in seven fathoms (Station 00?), we again find the white marl bottom already described for the region north of Murray Anchorage. There are here more large shell fragments and more living Orbitolites and Orbiculina than in the more northern area, but organisms in general are very few. The proportion of calcareous sponge and gorgonian spicules is considerable; the rest of the deposit, about 60 per cent, consists of very fine water-worn silt.

Still nearer the shore, around the ledges known as the "Pigeon Rocks," about half a mile from Crawl Point, at Stations 411, 412, and 416, in about three fathoms, shell sand again occurs, the bottom being very clean, with less than 5 per cent ooze, though varying much in coarseness, some of it being very fine indeed. The transition from marl, at Station 00?, to this deposit of sand is very sudden, and is no doubt due to the shoaling water and the surf action around these detached ledges. About one mile to the eastward, at the mouth of Bailey's Bay (Station 317) in two to three fathoms the bottom is again coherent, having 30 to 40 per cent ooze and being light gray. The coarse material consists chiefly of molluscan fragments and Foraminifera, with a few living bivalves, gasteropods, and fragments of echinoids and corallines. This station and the Bay itself are sheltered localities, where fine silt is readily deposited.

Close in along the shores of the main or Bermuda Island and St.

George's Island, in one to three fathoms, the bottom is again shell sand. Thus, just off St. Catherine's Point (Stations 438, 439, 440, and 441), in from one to two fathoms, the bottom is very clean, the sand being very coarse, white with a faint yellowish tinge, and with less than 1 per cent of ooze. Foraminifera form less than 10 per cent, and the great bulk, probably 50 per cent, of the sample consists of coralline and millepore fragments of large size, the remainder being mollusk shells, echinoid plates, Polyzoa, corals, and limestone fragments. The fragments are all much water-worn and honeycombed, and there are very few living organisms in the bottom. In this neighborhood there are many detached ledges, and in the shoal water along shore, where the scouring action of the waves is considerable, the bottom consists almost wholly of the coarse detritus from them, and from the shore cliffs.

In all other parts of the submerged lagoons, except those already described, the bottom deposits consist of shell sands and marl, occurring together in varying proportions. But in such of the lagoons as are broken by great numbers of small reefs, the proportions in which these two materials occur often differ widely in closely adjacent localities. In such basins the depths over the floor are usually very uniform, and the shoals and ledges rise very abruptly to near the surface. Their walls are often nearly perpendicular, very much honeycombed, and often undercut by the action of the water. Examples are the Brackish Pond Flats, the flats north of Ireland Island, and the Cow Ground Flats, two miles west of that island. The Brackish Pond Flats occupy the centre of the Bermuda Plateau, and consist of a perfect maze of shoals, deep channels, and basins. At different stations the bottom deposits are very different. Thus at Station No. 359, three miles northeast of the dockyard, in five fathoms of water, it is chiefly shell sand, composed of large living Foraminifera in great abundance, particularly Orbiculina, Orbitolites, and Pulvinulinae, molluscan fragments, living lamellibranchs and gasteropods, millepore fragments, a few coral fragments, worm tubes, corallines, and calcareous spicules, with about 25 per cent of very fine calcareous silt. At another station (No. 383 ?), in a small basin one mile directly north of the last, in seven fathoms of water, the bottom consists almost entirely of white marl, but contains also a considerable amount of broken shells and calcareous spicules, although very few living organisms. On the Cow Ground Flats the topographic conditions are very similar. At a station one mile directly west of the dockyards, in a cut between the ledges eight fathoms deep the bottom was white and coherent, with 80 per cent fine ooze or marl, the remainder being chiefly corallines and

millepores from the nearby ledges, with a few molluscan and other fragments.

Hogfish Cut is the only one of the several channels penetrating the boundary reef from which I have examined bottom samples. The collection contains five of these, from as many localities between the cut and the shore (Stations No. 430, 431, 434, 460, 461), which are almost indistinguishable. They are very clean, fine shell sand, whitish, with a faint pinkish tinge, with less than 1 per cent ooze. Although so clean, the sand itself is as fine as the bottom at Nonsuch Scaur. Foraminifera and their casts, especially Polystomella, form about 15 per cent; the remainder consists of corallines, mollusks, millepores, corals, ostracods, echinoderm remains, and Serpula tubes. There are very few living organisms of any kind in this sand, which resembles sand from Nonsuch Scaur so closely as to be almost indistinguishable from it.

From the area of the bank outside the boundary reef, between it and the thirty-fathom line, I have, unfortunately, no samples, and my only information is derived from the reports of fishermen and from what little could be seen through the water glasses. The vigorous growth of corals, gorgonians, millepores, etc., on the ocean faces of the reefs extends down to only about six or seven fathoms. Here begins the "broken ground" described by Agassiz (:95), as composed of various fragments and detritus from the reef itself; together with great numbers of nullipores. At about fifteen fathoms large sand patches appear, and in twenty fathoms the bottom is chiefly sand (admiralty chart).

General Considerations.

The study of these samples of sand from the shoal lagoons of the Bermuda Plateau is chiefly of interest for the light which it may throw on the method of growth of a limestone island in a latitude where reef-building corals are of but slight importance, and on the organisms chiefly concerned in this growth. The Bermudas, from their superficial resemblence to an atoll, and from the fact that their reefs are largely covered with corals, were considered as typical coral islands until the time of Agassiz's visit in 1895. It is from this point of view that Heilprin ('89) describes them, and Rein ('81) uses them as an example of an atoll in combating Darwin's theory of subsidence. Agassiz ('95) has, however, shown beyond possibility of doubt that this resemblance to a coral formation is purely superficial, that their ring-like form is due, not to coral growth, but to entirely different causes, and that coral has

entered but slightly into their formation; a conclusion which is supported by the composition of the modern sands.

The oceanic character of Bermuda — its great distance from the neighboring continent — prevents, as might be expected, its receiving any important access of material from the continental slope, and consequently its submarine deposits consist almost entirely of materials of clearly local origin. The great scarcity of remains of pelagic organisms, Globigerinae, Radiolaria, Pteropoda, and the like, is a striking feature of all the bottom samples examined; and this is especially interesting in connection with the results of our pelagic towing, from which we were forced to conclude that the pelagic fauna of Bermuda, on the north side of the islands at least, is very poor, both in species and individuals. On the southern exposure of the bank the conditions might prove to be different. But by far the greater area of the bank lies north of the land crescent, which forms an effectual barrier against any surface currents which might be caused by the prevailing southerly winds. Castle Harbor is the only sound to which water from the south has free access, and it is interesting to note that several tropical pelagic organisms, such as Velella, Charybdea, etc., have been taken here, but never on the northern side of the islands, while some species of fish are also known to occur only on the south shore. Shells of Spirula, however, are found in considerable numbers on all of the beaches. The only objects found which might possibly be of volcanic origin were a few small particles of pumice.

The great bulk, at least 90 per cent, of all the bottom deposits, whatever their nature, is composed of calcareous material. Siliceous materials are exceedingly small in amount, and consist chiefly of the spicules of various organisms, there being no siliceous particles of terrigenous origin.

One of the most striking features of all the beaches and submerged sands is the complete absence of any true coral sand, and the great rarity of coral fragments of any kind. This is, of course, strictly in agreement with the fact that the Bermudas are in no sense a coral island, and that coral has had practically nothing to do with their formation and growth. Corals, of course, flourish on the reefs, but form merely a thin incrustation over the underlying aeolian ledges. That they do not enter more largely into the sands is due chiefly to the character of the forms occurring here. In all coral islands and coral reefs it is the madrepores which are chiefly responsible for the formation of sand, these being delicate and easily broken up. But here, as observed by Agassiz ('95, p. 235), the corals are mostly gorgonians, which are of course of no importance in

this connection, and porites, astraeans, meandrinas, and oculinas; massive, stony forms, too solid to be ground up except by the very heaviest surf, which occurs only on the south shore. I should add that in speaking in general of corals, I have not meant to include the millepores, which have been of great importance in sand-building, as noted by Heilprin ('89).

The bottom deposits of Bermuda fall into three main types: first, the blue muds; second, the white marls; and third, the shell sands. Of course these may be combined in any one locality, but in their features they are tolerably distinct. The blue muds occur only in small, more or less landlocked basins which are cut off by bars or islands from any active circulation of sea water. They seem to be chiefly of terrigenous origin, being the fine detritus washed down by the rains from the surrounding calcareous hills, together with some vegetable remains. They are relatively bare of animal life, except for a few worms and for the sea urchins, which, as in Mullett Bay, may live in them in extraordinary numbers; and they agree perfectly in their mode of origin with the blue muds of the continental slope. The areas where they occur are so limited that they are of little practical importance and need not be further considered.

The white marls consist of white calcareous sand so fine as to form a chalky ooze, containing very few living organisms or recognizable remains. They occur chiefly in the deep basins of shallow waters in sheltered localities where there are no strong currents, and in the neighborhood of cliffs, ledges, and reefs. They are formed, as stated by Agassiz ('95), by the "slow trituration of aeolian rock."

A good example of the origin of these marls is afforded by the Cow Ground Flats, just west of Ireland Island, where there are innumerable banks and ledges, enclosing many small channels and basins, which have a depth of about seven fathoms. For some reason the mechanical destruction by the action of the water on these aeolian rocks is very rapid here, and the silt thus formed, which is of almost impalpable fineness, is being deposited in large quantities in the protected basins between the ledges. During strong winds the waters over the whole lagoon are often milky with the great quantity of this silt which they hold in suspension (Agassiz, '95, p. 212). In certain restricted localities, as mentioned above, the white marl forms almost the entire mass of the bottom deposit, and it is mixed in greater or less degree with the various deposits of shell sand.

The shell sands are composed of rather coarse fragments, with great numbers of living organisms, with, in every case, a considerable ad-

mixture of marl, and of various sorts of silt, calcareous and siliceous spicules, and the like. The organisms chiefly active in the formation of the shell sands are corallines, mollusks, tube-building worms, millepores, and Foraminifera, varying in their relative importance in different localities. Algae probably form the greatest mass of the sand, the most important genera being those described from the Castle Harbor sands. Large sand-dwelling Foraminifera form nearly half of the entire bottom deposits in certain restricted localities, the most abundant forms being Orbitolites duplex, Orbiculina adunca, Bulimina, Cornuspira foliacea, Pulvinulina menardii, Textularia concava, T. luculenta, Ammodiscus tenuis, and a species of Trochammina.

The chief deposits of shell sand occur in rather shoal water, or in the channels or other places where there are tidal currents, or at least strong currents of water. They may mark areas either of the growth of organisms or of deposition; the former being localities, such as parts of Castle Harbor and Castle Roads, where sedentary organisms, chiefly corallines, Foraminifera, and mollusks, flourish in the sand. It is in such places that the larger Foraminifera reach their greatest abundance. But these localities of growth are comparatively rare and restricted, by far the greater part of the shell sands marking areas of deposition of the coarse detritus from the reefs and ledges and from the littoral zone. Such sands are coarsest along shore, for example off St. Catherine's Point, and on the shoalest bars, as in Great Sound, where the action of the surf and of currents reaches its maximum; they decrease steadily and regularly in coarseness as the depth increases, until, as in Hogfish Cut, they may be very fine indeed, though still washed clean of fine ooze by the tides. In these sands, built of the organic fragments from the neighboring ledges, corallines and millepores are of the greatest importance, while mollusks and Foraminifera constitute but a small portion of the deposits. The reefs, as in true coral islands, contribute far more to the sands of the lagoon than do the sand-dwelling organisms, despite the local abundance of the latter. Heilprin ('89), it is true, thought that "all the sand being formed at present is derived from the destruction of existing land masses," that is, either marl or coarser limestone detritus; but I believe that the organic mains, which are constantly settling down from the reefs to the bottom, are in much greater bulk. It is, however, exceedingly difficult to estimate the relative importance of the marl and the shell-sand deposits over the plateau, since they always occur together, though in varying proportions. No doubt the formation of marl over many parts of the plateau is rapid; so rapid

that it results in the choking of all organisms on the bottom, except where tides or waves sweep it away. A good example of such distribution of deposits is seen in Murray Anchorage, where, in the sheltered northern half, the bottom is almost wholly marl, while in the Ship Channel near by there is a strong tidal current and a bottom of shell sand. A striking example of the silting in of sedentary organisms was found by Herdman (:03) in his study of the pearl oyster beds of Ceylon, where, during a single year, a bed of several millions of young oysters was destroyed and entirely hidden by shifting sands.

Heilprin ('89) emphatically denies the supposition that solution can have any significant effect in keeping the lagoons and channels open; it is certain that the marl and shell sand are building up and levelling the surface of the plateau much faster than the water can possibly dissolve it, by which, however, I do not mean that the surface of the bank is as a whole rising. Agassiz ('95) has already shown the great importance of the solvent action of sea water on limestones in honeycombing and undermining cliffs and ledges, and in certain localities the same action is clearly shown in the worn and honeycombed condition of the shells and other fragments in the sand.

List of Stations at which Bottom Samples were collected.*

No.				Map No.
		1903.		
313.	64° 43′ 47″ W.;	32° 20′ 18″ N.	Off Crawl Point, 5 fathoms.	3
314.	64° 42′ 50″ W.;	32° 20′ 45″ N.	N. of [Bailey's] Bay Id., 8 fms.	2
317.	64° 43′ 03″ W.;	32° 20′ 30″ N.	Mouth of Bailey's Bay, 3 fms.	3
319.	64° 51′ 07″ W.;	32° 18′ 10″ N.	Mangrove Bay.	4
323.	64° 50′ 32″ W.;	32° 19′ 24″ N.	West of Ireland Id., 7 fms.	4
324.	64° 43′ 50″ W.;	32° 25′ 15″ N.	Three Hill Shoals, 8½ fms.	1

* The position of each of the various stations is indicated on the accompanying maps by two marginal lines, one for latitude and one for longitude. After the maps were prepared it was discovered that there was a discrepancy of about 20″ in latitude between the British Admiralty Chart, on which Map 1 is based, and the recent Ordinance Survey Map, on which Maps 2–4 are based. A correction of *plus* 20″ is to be applied to the *latitude* of any place indicated on Maps 2–4 to bring it to the corresponding place on Map 1; or a correction of *minus* 20″ to places on Map 1 to make them fall at the right place on Maps 2–4.

The location of any given station was determined on one or other of these maps, and the latitude and longitude here recorded is that of the given place *on that map*. Where the haul extended over some distance, the middle point of the haul is the one noted on the map. — E. L. M.

355. 64° 41′ 05″ W.; 32° 22′ 05„ N. Mullet Bay. 2
356. 64° 40′ 30″ W.; 32° 20′ 40″ N. (approximately). Centre of Castle Harbor, 6 fms. 2
359. 64° 46′ 10″ W.; 32° 21′ 10″ N. Brackish Pond Flats, 5 fms. 1
366. 64° 50′ 12″ W.; 32° 15′ 17″ N. Little Sound, 9 fms. 4
1407. 64° 38′ 58″ W.; 32° 21′ 45″ N. Smith's Sound, 4 fms. 2
1408. 64° 39′ 15″ W.; 32° 21′ 36″ N. Dolly's Bay, 3 fms. 2
1409. 64° 38′ 57″ W.; 32° 21′ 56″ N. St. George's Channel, 4 fms. 2
1413. 64° 39′ 40″ W.; 32° 20′ 05″ N. Castle Roads, 5 fms. 2
1416. 64° 44′ 00″ W.; 32° 21′ 10″ N. Ship Channel, near Crawl Flats, 6½ fms. 1
1417. 64° 43′ 18″ W.; 32° 22′ 21″ N. South Side of Murray Anchorage, 8 fms. 1
1418. 64° 42′ 18″ W.; 32° 22′ 38″ N. South Side of Murray Anchorage, 8 fms. 1

1904.

383. 64° 47′ 45″ W.; 32° 22′ 20″ N. Brackish Pond Flats. 1
393. 64° 43′ 59″ W.; 32° 18′ 59″ N. Flatts Inlet. 3
402. 64° 42′ 15″ W.; 32° 21′ 13″ N. W. Entrance Ferry Reach. 2
404. 64° 43′ 02″ W.; 32° 19′ 35″ N. Harrington Sound. 3
406. 64° 38′ 47″ W.; 32° 21′ 57″ N. Entrance St. Geo. Channel. 2
407. 64° 39′ 12″ W.; 32° 20′ 33″ N. Nonsuch Scaur. 2
408. 64° 39′ 08″ W.; 32° 20′ 28″ N. Nonsuch Scaur. 2
409. 64° 39′ 40″ W.; 32° 20′ 00″ N. Castle Roads. 2
411. 64° 43′ 20″ W.; 32° 20′ 28″ N. Near Pigeon Rocks. 3
412. 64° 43′ 30″ W.; 32° 20′ 28″ N. Near Pigeon Rocks. 3
415. 64° 43′ 45″ W.; 32° 20′ 17″ N. Off Crawl Point. 3
416. 64° 43′ 22″ W.; 32° 20′ 30″ N. Near Pigeon Rocks. 3
418. 64° 48′ 27″ W.; 32° 16′ 53″ N. North Shore of Long Island. 4
419. 64° 48′ 32″ W.; 32° 16′ 52″ N. North Shore of Long Island. 4
420. 64° 48′ 35″ W.; 32° 16′ 52″ N. North Shore of Long Island. 4
421. 64° 48′ 10″ W.; 32° 17′ 05″ N. Two Rock Passage. 4
422. 64° 47′ 55″ W.; 32° 17′ 25″ N. Mouth of Fairyland Creek. 3
423. 64° 48′ 32″ W.; 32° 18′ 03″ N. Cobbler's Cut. 4
427. 64° 45′ 10″ W.; 32° 27′ 30″ N. North Ledge Flats. 1
428. 64° 45′ 10″ W.; 32° 26′ 30″ N. Northwest of Three Hill Shoals. 1
429. 64° 45′ 10″ W.; 32° 25′ 20″ N. West of Three Hill Shoals. 1
430. 64° 52′ 20″ W.; 32° 15′ 03″ N. Hogfish Cut. 4
431. 64° 52′ 18″ W.; 32° 15′ 12″ N. Hogfish Cut. 4

434.	64° 52′ 18″ W.;	32° 15′ 16″ N.	Hogfish Cut.	4
438.	64° 39′ 43″ W.;	32° 22′ 58″ N.	Off St. Catherine's Point.	2
439.	64° 39′ 50″ W.;	32° 22′ 55″ N.	Off St. Catherine's Point.	2
440.	64° 39′ 50″ W.;	32° 23′ 00″ N.	Off St. Catherine's Point.	2
441.	64° 40′ 00″ W.;	32° 23′ 05″ N.	Off St. Catherine's Point.	2
447.	64° 39′ 17″ W.;	32° 22′ 10″ N.	Higg's Cut.	2
448.	64° 39′ 20″ W.;	32° 22′ 16″ N.	Town Cut.	2
451.	64° 39′ 12″ W.;	32° 20′ 30″ N.	Nonsuch Scaur.	2
452.	64° 39′ 03″ W.;	52° 20′ 32″ N.	Nonsuch Scaur.	2
454.	64° 40′ 20″ W.;	32° 21′ 28″ N.	North Side of Castle Harbor.	2
456.	64° 48′ 55″ W.;	32° 16′ 05″ N.	Between Burt Island and Darrell Island.	4
458.	64° 50′ 36″ W.;	32° 15′ 51″ N.	Between Tucker's Island and Morgan's Island.	4
459.	64° 49′ 50″ W.;	32° 17′ 36″ N.	North of Great Sound.	4
460.	64° 52′ 28″ W.;	32° 15′ 25″ N.	Near Hogfish Cut.	4
461.	64° 52′ 20″ W.;	32° 15′ 20″ N.	Near Hogfish Cut.	4
463.	64° 47′ 25″ W.;	32° 16′ 23″ N.	Near Godet's Passage.	3
466.	64° 49′ 20″ W.;	32° 16′ 55″ N.	Between Hawkin's Island and Lambda Island.	4
467.	64° 38′ 48″ W.;	32° 20′ 37″ N.	Long Bay, Cooper's Island.	2
468.	64° 38′ 40″ W.;	32° 20′ 34″ N.	Long Bay, Cooper's Island.	2
470.	64° 43′ 20″ W.;	32° 19′ 35″ N.	Harrington Sound.	3

The Challenger Bank.

The Challenger Bank lies southwest of the Bermuda Bank, from which it is separated by a channel nine miles broad, and one thousand fathoms deep at its deepest part. Thus it forms a fairly independent elevation of the sea floor. If we take the one-hundred-fathom line as its margin, it is seven miles long (north and south) by six miles broad, covering an area of about forty square miles, and is roughly oval in outline. In its shoalest spot it rises to within twenty-four fathoms of the surface, but over most of its area the depth is between thirty and forty fathoms. Between the Bermuda and Challenger banks a single sounding of one thousand fathoms has been made (Agassiz, '95, Pl. II, fig. 1), and between the latter and the Argus Bank, which lies eight miles to the south, one of five hundred and thirty fathoms. One and one half miles northwest of the one-hundred-fathom line of the Challenger Bank, the depth is given on the admiralty chart as twelve hundred and fifty fathoms, a slope

of about forty degrees. But on the eastern side the slope to a depth of seven hundred fathoms is more gradual, being about twenty-five degrees. The bank has thus the character of a very steep, isolated peak, some six thousand feet high. Although the sounding of five hundred and thirty fathoms shows that there is a ridge connecting the Challenger and Argus banks, on each side of which the water is much deeper, this in no way interferes with the isolated character of the bank as far as its fauna and bottom deposits are concerned.

Dredging on this bank was carried on from an ocean-going tug from July 31 to August 2, 1903, hauls being made at a number of stations.* Bottom samples were obtained from depths between thirty and fifty fathoms.

The only dredging ever done before on this bank was carried on by the Challenger, in April, 1873, when a single haul was made while the ship was anchored to allow soundings to be taken. Speaking of the results of this haul, Sir Wyville Thomson ('**77**, I, p. 360), says, "The bank, which seems to be about five miles across, consists mainly of rounded pebbles, of the substance of the Bermudas 'Serpuline reef.' There is an abundant growth all over the pebbles of the pretty little branching corals Madracis asperula and M. hillana." Murray and Renard ('**91**, p. 50–51), in their report on the deep-sea deposits collected by the Challenger, say that the bank is covered with corals, Serpula, and calcareous pebbles. Since that time the area of the bank has been developed by careful soundings, and the bottom is given on the admiralty charts as coral sand; but, so far as I am aware, no other dredging has ever been done on the bank.

Our dredge hauls brought up the same organisms as those taken by the Challenger; that is, Madracis, gorgonians, starfishes, mollusks, etc., together with large numbers of the calcareous pebbles, with which the dredge was ordinarily filled to the mouth. These pebbles ranged from two to six inches in diameter, the latter being the largest that could pass through the mouth of the dredge; but of course much larger ones may occur. Neither sand nor mud was brought up by us; in fact, no deposits whatever except these calcareous masses. These are roughly spherical and of a dark red or brownish color, being entirely incrusted with the nullipore Lithothamnion ungeri, and with Serpula tubes, small corals, bryozoans, and other organisms. Every one of these masses, although entirely coated with organisms, showed on one side or region nul-

* For this opportunity the Biological Station was indebted to Captain William E. Myer of St. George's, who generously gave the use of his tug "Gladisfen" and her crew for this purpose.

lipores that were dead; this side evidently had recently been undermost. They thus agree exactly in external appearance with the "pebbles" of the Challenger. But while both Thomson and Murray believed them to be composed of the same material as the Bermuda serpuline reefs, that is, of aeolian limestone, careful examination has shown them to be of an entirely different origin. When sawed into slices, the sections show that the pebble is composed of successive, more or less regularly concentric layers of Lithothamnion, together with a few worm tubes, bryozoans, and other incrusting organisms. The whole mass is more or less porous, often honeycombed by the borings of mollusks (Lithophagus), and the looser regions alternate with more compact layers. The mode of growth has evidently been that of successive depositions of lime by nullipores around some small central core, which may be very minute. This is not, of course, in any sense of the word a pebble, but is a true nullipore "head," in no way to be confounded with either aeolian pebbles or the mechanical concretions of lime or siliceous materials so often dredged in deep water.

The spherical form of these heads is of considerable interest. Such spherical nullipore masses occur very commonly in shoal water, either as concretions about some core, or as independent stalked growths, which eventually become detached and free to roll about. Such forms have been taken in great numbers off Eastport, Me., in a few feet of water, and also in many other localities where they are well within the sphere of wave action, and probably owe their spherical form to the fact that they are frequently rolled over and over. Such spherical masses have also been previously dredged in deep waters, where their mode of growth has been something of a problem. That some such process of wave action is at work on the Challenger Bank seems probable from the spherical form and worn appearance of the concretions, the latter condition being made evident by the broken nullipore branches. Without being occasionally overturned they would not attain a spherical form, but would probably take on forms similar to those of porites, astraeans, or other fixed massive corals. To account for the amount of disturbance of the bottom necessary to explain such spherical concretions, we must turn to a consideration of wave action; neither tides nor currents being sufficiently strong in this locality to afford an explanation.

Statements as to the depth to which the action of storm waves may extend are conflicting and unsatisfactory in the extreme. While it is often claimed that one hundred feet marks the limit to which wave action is important in the transference of material, I am assured by Professor

W. M. Davis that the oscillations can probably be detected to a depth of several thousand feet. Moreover, Alexander Agassiz ('88ª, p. 273) writes that off the New England coast disturbing forces due to the action of waves, tides, and currents may extend perhaps to a depth of nearly three hundred fathoms. But in this case currents are probably chiefly concerned. More definite and satisfactory are the opinions of Admiral Wharton ('97), who has suggested that the depth to which the action of waves extends may be indicated by the change of slope generally taking place off shore below a depth of eighty to one hundred fathoms; and, further, that the existence of banks in the open sea at a depth of from thirty to forty fathoms may show the limit of depth to which oceanic waves may cut down a land mass on which they act. Agassiz (:03ª, p. xviii.) also thinks there is good evidence of such submarine denudation. At first glance the Challenger Bank seems to present a good example of such a worn-down bank; dredging has shown, however, that its surface is not undergoing a process of denudation, but rather one of growth.

If we can accept Admiral Wharton's conclusions, — and they rest upon a much sounder basis than the earlier views which limited wave action to lesser depths, — we shall find in wave action, and especially in the oscillations of storm waves, a sufficient explanation for the present problem. I am convinced that the frequent movements of the nullipore concretions, which undoubtedly occur, are brought about in this way; and I consider the occurrence of such spherical concretions on the bank good evidence that at a depth of from thirty to fifty fathoms the action of storm waves is often of considerable force.

The dredgings from the Challenger Bank add to the evidence already accumulated to prove the great importance of nullipores as reef builders. The active rôle which they play in the economy of coral reefs, especially on the sea faces, and in localities where the corals are dead or dying, has been emphasized by Agassiz ('88ª, p. 82), who, writing of the Florida reefs, says, "Immense masses of nullipores and corallines grow on the shallowest flats at the tops of the branches of madrepores which have died from exposure to the air." J. Stanley Gardiner ('98, pp. 501, 502), in his studies on the island of Funafuti, also comes to the conclusion that they take a very important part in the building up of a coral reef. They are not, however, limited to shallow waters, but occur at considerable depths, being absolutely limited only by the absence of sunlight. Thus Agassiz ('88) found them smoothing over the modern limestones on the Pourtales Plateau, in depths of from ninety to three hundred fathoms, and in the borings at Funafuti nullipores seem to be the most important

of all rock-building organisms, even at the extreme depth of 1120 feet, a depth of course well within their ordinary bathymetric distribution, as shown by the Pourtales Plateau. Apart from the considerable amount of material which they may add to any shoal, the great importance of the incrusting nullipores lies in their solidifying and cementing action. Thus, on the sea face of a reef, they are most effective in protecting it against the force of the surf, as, for example, in the case of the Bermuda serpuline reefs, a function which they share chiefly with the tube-building annelids. In the upbuilding of submarine banks they carry on a very similar process. The events now going forward on the Challenger Bank are probably as follows. The nullipores gradually form incrusting masses about various objects, or grow up independently on stalks which later become broken; in these ways the spherical concretions begin. Lying free on the bottom, subject to the action of the waves, they are occasionally turned during their growth so that they retain a spheroidal form, until at last they can no longer readily be moved; whereupon, lying motionless side by side, they become cemented together by the incrusting organisms, and thus come to form a solid modern limestone, which is produced much more rapidly than that which is formed from the loose shell sands. This process taking place over the Challenger Bank, where there is no direct evidence of either elevation or subsidence, has raised it to within some thirty to fifty fathoms of the surface of the sea; a depth where a few corals already flourish. If we imagine this process as continuing until the bank rises to within about twenty fathoms of the surface, we should then have excellent conditions for the formation of a coral reef. Of course in such upbuilding the nullipores constitute only a part, though a most important one, of the whole growth; the tests of Foraminifera, and the remains of other lime-secreting organisms, add largely to the accumulation of material.

The reports of the borings in Funafuti, a true coral island of the Ellice group, recently published (Bonney and others, :04) by the Royal Society of London, are of special interest in this connection. After two unsuccessful attempts, the drill was finally driven to a depth of 1114 feet, and the cores have since been carefully studied. Dr. G. J. Hinde has given (pp. 186–361) an elaborate account of the organisms; and the evidence goes to show that whether in the form of solid rock cores, or as incoherent granular particles, the material is entirely of organic character, traceable to the calcareous remains of animals and algae, of which Halimeda and Lithothamnion occur in greatest abundance. Professor Judd remarks that "from top to bottom the same organisms occur,

sometimes plants, sometimes Foraminifera, and sometimes corals predominating"; and Mr. Finckh (p. 133), studying the biology of these reef-forming organisms, judges their relative importance to be in the following order: (1) Lithothamnion, (2) Halimeda, (3) the Foraminifera, (4) Corals.

In dredging on the sea slopes of the Funafuti atoll Lithothamnion was found abundant down to two hundred fathoms, and it plays a very important rôle in the modern reefs. One observation of particular interest was on the growth of a cluster of Halimeda (p. 146), which in six weeks attained a height and thickness of three inches.

The most interesting feature of the report, as far as concerns our study of the Challenger Bank, is the very great importance attaching to the coralline algae, both in the modern reefs and in the older rocks, as shown by the core from the borings. Putting aside all question as to changes of level of the sea floor, there can be no doubt that the corallines, with slight aid from other organisms, are capable of building limestones of great thickness; and I believe that they will be found to enter into the composition of most limestone banks, particularly those which, like Bermuda and the Challenger Bank, lie outside the belt of vigorous coral growth. To complete the survey of what I may call the "Bermuda range," it is most desirable that an examination should be made of the Argus Bank, which rises to within eight fathoms of the surface. No doubt, thanks to the shoal water, it will be found much more thickly covered with corals and gorgonians than the Challenger Bank; but in all probability its foundations and structure are the same, and I think we may consider the Challenger and Argus banks as two stages in the growth of such an exposed peak as the Bermudas.

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THE ACHROMATIZATION OF APPROXIMATELY MONOCHROMATIC INTERFERENCE FRINGES BY A HIGHLY DISPERSIVE MEDIUM, AND THE CONSEQUENT INCREASE IN THE ALLOWABLE PATH-DIFFERENCE.

By R. W. Wood.

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By R. W. Wood.

Presented by C. R. Cross, October 12, 1904. Received September 6, 1904.

The results recorded in the present paper were, for the most part, obtained during the progress of an investigation of the dispersion of sodium vapor. As I have mentioned in the previous paper, the path-difference under which it is possible to obtain interference-fringes with helium (D_3) light can be more than doubled by the introduction of a small amount of sodium vapor into the path of one of the interfering beams. This development of fringes far out in the system by the dispersive action of the vapor is accompanied by their complete disappearance at the centre of the system, where the difference of path is zero.

In order to understand this action of the vapor we must first consider briefly the conditions under which fringes may be visible.

Suppose that we have a system of circular fringes formed with white light, and consider a point just outside of the visible ring system, where the illumination appears uniform. Our fringe system is built up of an infinite number of colored systems which are in coincidence at the centre, but which get more and more out of step as we advance out into the system, owing to the fact that the "scale" on which the Newton rings are formed decreases with decreasing wave-length. Let us now consider in what manner fringes may be made to appear at a point where the overlapping is so great as to destroy all trace of the fringes; in other words, how may achromatization be more or less completely secured.

It appears to me that there are only two conceivable ways in which the result can be obtained. If we could, by the introduction of a dispersing medium, increase the diameters of the blue rings without generally affecting the diameters of the red ones, it is obvious that we should greatly increase the number of visible fringes without, however, altering their distinctness at the centre of the system.

A slight inclination of either of the back mirrors of the interferometer increases or diminishes the scale on which the fringes are formed, and since a similar change in the direction of the reflected rays can be effected by the introduction of an acute prism, it is easy to see that, owing to the dispersion of the latter, the change in the scale will be different for the different wave-lengths, more or less perfect achromatization resulting.

The introduction of a medium into the path of one of the interfering beams causes a shift of the fringe system as a whole, and if the medium is dispersing the shifts will be different for the different colors. The red, green, and blue fringes, which are out of step at a given point, may thus be brought into coincidence by the inequality of their respective displacements. In this case, however, since the systems are shifted as a whole, the fringes will be thrown out of step at the centre of the system, consequently we have obtained an increase in the distinctness far out in the system, at the expense of distinctness at the centre. This is precisely what happens in the case which we are considering.

It has been found in every case that the introduction of sodium vapor into one path of the interferometer increases the distinctness of the fringes in a portion of the system which is brought into the field of the instrument by increasing the length of the other path.

We will now consider the case of the helium fringes, which under ordinary circumstances disappear when the path difference is between 1.5 and 2 cms., there being no recurrence of visibility by further increment of path difference, as in the case of sodium light. We must therefore regard the helium (D_3) line as a single line of finite breadth or a close group of lines. In Figure 1 let BC represent the intensity curve of the helium light, C being the edge of shorter wave-length. Immediately above we have a schematic representatation of the fringe system, with its centre at A. Light from the side B of the D_3 line will produce the fringes indicated by the dotted line, which are farther apart than the fringes formed by the light of shorter wave-length coming from the side C of the line. There will, in addition, be an infinite number of other systems formed by light of wave-lengths intermediate between B and C which I have indicated by light shading.

Now suppose sodium vapor to be introduced into one path of the instrument, and the whole system shifted slightly to the left in consequence. Owing to the enormous dispersive power of the vapor, the dotted system (longer λ's) will be shifted more than the other, since the D_3 line lies on the blue side of the sodium absorption-band, and the change in the velocity of the light is greatest for the longest waves, namely, those on the B side

of the line. The result of this dispersive action is that the fringes are brought into step at a point D, to the right of the centre, thrown out of step at the centre, and still more out of step to the left of the centre. If we had but the two systems indicated by the solid and dotted lines, it is obvious that the systems would come into step again to the left of the centre, a condition which would occur if D_3 consisted of two infinitely narrow lines very close together. In the actual case the presence of waves of lengths intermediate between those of B and C make such a recurrence of visibility to the left of the centre impossible, and we have distinct fringes to one side only of the original centre of the system. On increasing the density of the sodium vapor, the point D of maximum visibility moves further along to the right, and to keep the fringes in the field it is necessary to turn the screw of the instrument in such a direction as to cause

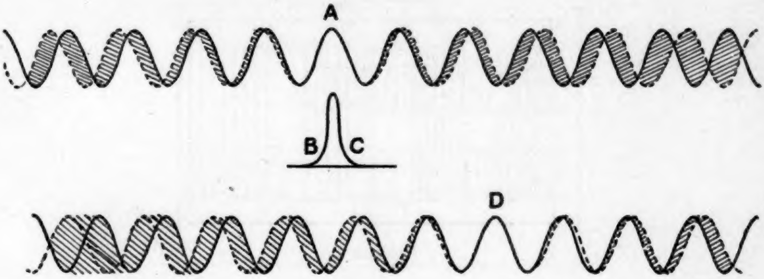

Figure 1.

the system to move in *the same direction* as the shift due to the sodium vapor.

Now the sodium vapor accelerates the helium light, since its refractive index is less than unity for light of shorter wave-length than that of D_2, consequently the reduced path is less. To shift the fringes in the same direction as that resulting from the shortening of the path through the sodium vapor, we must *lengthen* the other or air-path, which is precisely what was found to be the case, as I have already said.

If the D_3 line lay on the other side of the D lines, the shift would be in the opposite direction, i. e. to the right, and we might at first sight expect the point of maximum visibility to shift to the left of the centre. We must, however, remember that in this case the change of velocity is greatest for the *shortest* waves on the side C of the line; consequently the system indicated by the solid line will suffer the greatest displacement,

and we shall have coincidence at D, to the right of the centre, exactly as before. To test this point experimentally, the interferometer was illuminated with light from the monochromatic illuminator, a narrow band on the green side of the D lines being utilized. The formation of sodium vapor in one of the paths gave rise to the same changes as were produced in the case of the helium light, it being necessary to increase the air-path to prevent the fringes from disappearing. If the fringes were made very narrow, so as to occupy only a small portion of the field, the wandering of the system to one side could be easily watched, as the sodium vapor was formed. It must be understood that only a very small actual *displacement* occurs, the wandering of the system being merely a change in position of the region over which fringes can be seen. On repeating the experiment with a band of approximately monochromatic light on the red side of the D lines, a similar drift of the position of maximum visibility

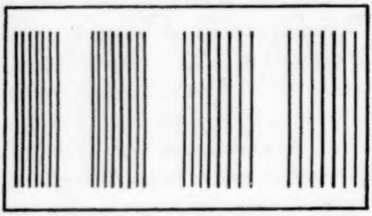

FIGURE 2.

was observed, and the direction of the drift was the same as before. In the case of helium light I have been able to increase the path difference to five or six centimeters, or to nearly treble it.

The achromatizing action of the sodium vapor is most beautifully shown if we illumine the interferometer with white light.

Under ordinary conditions, only two or three white fringes are seen, bordered on each side by perhaps a dozen rainbow-colored bands, which fade rapidly into a uniform illumination. If sodium vapor is formed in one of the interferometer paths, the colored fringes rapidly achromatize, and increase in number, breaking up, however, into groups, as shown in Figure 2. As the density of the vapor increases the number of groups increases, each group, however, containing fewer fringes. The position of the centre of the grouped system drifts in the same direction, as the point of maximum visibility in the previous experiments.

The explanation of the altered appearance of the fringes in this case is not as simple as in those previously considered. We are dealing with two

wide ranges of wave-lengths on opposite sides of the absorption-band. The fringe shifts of the two spectral regions will be in opposite directions, while the drifts of the points of maximum visibility will be in the same direction. It appeared as if this might increase the width of the region over which fringes could be observed, for the red-orange fringes are shifted in one direction and the yellow-green in the opposite. Each set would be more or less perfectly achromatized, and in the region in which they overlapped we should expect a periodic visibility, owing to the difference in the widths of the fringes of the two systems.

To test the point it seemed best to work with a narrow range of the spectrum symmetrical about the D lines. This was obtained by opening the slit of the monochromatic illuminator, bisecting it with a wire, and adjusting the prisms so that the region of the D lines was screened off by the wire. By means of a small screen either of the two narrow portions of the spectrum bordering the D lines could be screened off.

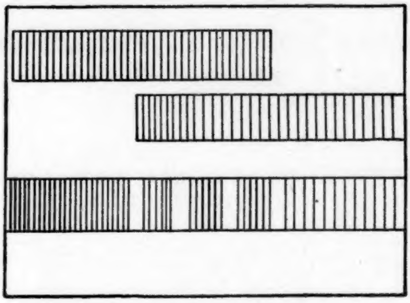

FIGURE 3.

The effect of the sodium vapor on the fringes formed when the interferometer was illumined by either one or both of the two portions of the spectrum could then be studied at leisure.

It was found that when a considerable amount of the vapor was present the apparent centre of the greenish-yellow fringe system was widely separated from the centre of the orange-yellow system.

When both sorts of light were used at once there was a periodic visibility in the region in which the two systems overlapped, the appearance in the three cases being shown in Figure 3.

The case is a little more complicated when white light, or the entire spectrum, is used, but it does not differ materially from the special case just considered.

Practically the same thing occurs when the interferometer is illuminated with sodium light, except that in this case the density of the sodium vapor in the optical path must be very much smaller. A periodic visibility results even when the light of one of the D lines is removed by the polarizing system described in the previous paper. The case is of course similar to the last-mentioned, for the width of the D line illuminating the instrument is greater than the width of the absorption-band of the rare vapor. We thus have a condition identical with that which we had when the emitting slit of the monochromatic illuminator was bisected with a wire which cut out the D lines from the narrow band of the spectrum which was utilized.